

SO₃ Gas-Phase Cleaning Process

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EXECUTIVE SUMMARY

ANON INCORPORATED is engaged in an enterprise to develop, manufacture and market gas-phase processing tools for removing photoresist and other organic materials from substrates used in the manufacture of semiconductor integrated circuits (ICs), flat panel displays, thin-film heads, printed circuit boards and other devices.

The Company has developed a novel cleaning method for removing photoresist and organic polymers from semiconductor wafers. This non-plasma method uses anhydrous sulfur trioxide gas in a two-step process, during which, the substrate is first exposed to SO₃ vapor at relatively low temperatures (< 150°C) and then is rinsed with de-ionized (DI) water. The process is radically different from conventional plasma-ashing methods in that the photoresist is not etched or removed during the exposure to SO₃. Rather, the removal of the modified photoresist takes place during the subsequent DI-water rinse step. The SO₃ process completely removes photoresist and polymer residues in various post-etch applications, and is considered an “enabling” technology for new products in the semiconductor industry.

Additional advantages of the process are absence of halogen gases and elimination of the need for other hazardous, toxic solvents and wet chemicals. Thus, the process enjoys a low cost of ownership and has minimal environmental impact. Commercialization of ANON’s process will have a significant impact on the growth of the semiconductor, flat-panel display, and other related electronic manufacturing industries.

Under a 1995, Department of Energy (DoE) NICE³ Grant (#NIC-95-082), administered by the California Energy Commission (CEC), and a 1996, California Trade and Commerce Agency (CTCA) matching award (C95-0230), ANON developed its second-generation, R&D tool, “CRITERION-1000™”, based on the work with an earlier, more primitive exposure tool. The CRITERION-1000™ was used to develop and optimize process recipes for a broad range of strip/clean applications. These development efforts were carried out with the help of semiconductor manufacturers at ANON facilities. The results of the process optimization efforts were used in the design of ANON’s production tool, CRITERION-2000™.

In March 1998, the federal NICE³ contract with ANON was modified and extended (#NIC-95-082 A1). ANON was also awarded a new CTCA grant (C97-0074) for further development of its process. A cost-sharing project was designed to include process development efforts that would lead to installation of beta-site tool at a major IC manufacturer location for evaluation. ANON also undertook to separately fund parallel development and manufacture of the CRITERION-2000™ production tool, for beta installation.

During the new grant period, ANON has successfully carried out the tasks related to the process development. Intensive testing programs were established with several major IC manufacturers in the US and Japan as potential targets for beta development programs. Joint development programs were also established with the manufacturers of semiconductor materials and equipment for the integration of SO₃ process in device manufacturing processes. As a result of these efforts, we have successfully demonstrated that ANON’s SO₃ strip/clean process can replace the existing ash and wet clean processes both in the conventional post-etch and implant as well as the emerging low-k dielectric applications in the semiconductor industry. Successful applications of ANON’s SO₃ strip/clean process for the flat-panel device manufacturing were also demonstrated.

During this grant period, ANON also completed the architecture and market specifications of the CRITERION-2000™ production tool. ANON also completed the chamber design layout and the robot and interface specifications. However, ANON was not able to secure the needed private funding to embark on the construction of the CRITERION-2000™ in time for the completion of the project. Nevertheless, ANON continued with the design of the chamber and gas delivery system, qualifying robot, platform and interface suppliers, and in-house evaluation of the spin-rinse-dry subsystem. Negotiations are in progress for the supply of a platform and control software. As a result, ANON expects to complete the construction of its the CRITERION-2000™ tool in 6-9 months after the end of the current grant period.

A. BACKGROUND:

The semiconductor capital equipment industry provides a range of different manufacturing equipment to semiconductor manufacturers around the world. Specialized, and often very complex, equipment is sold for installation in semiconductor factories, called wafer fabs, to manufacture silicon wafers containing multiple, and identical, copies of semiconductor devices ready for packaging and final testing. In 1998, the market for wafer fab equipment was over \$14 billion and is expected to grow to over \$16 billion by the year 2000.

The semiconductor industry, which buys manufacturing equipment from companies such as ANON, is a large, dynamic industry (over \$122 billion in 1997 and anticipating over \$182 billion in revenue by 2001). In this industry, manufacturing technology is a major determinant of the size, the speed, the cost, and the capability of the product designs that can be offered by semiconductor manufacturers. Consequently, when manufacturers construct new wafer fabs, advancing their manufacturing technology is often a leading priority when it comes to selecting the manufacturing equipment for installation. A convenient parameter for measuring this technological capability is the minimum feature size of devices that can be economically manufactured in the wafer fab. Today, for example, advanced semiconductor designs may contain devices with 0.25 micron features, or smaller. The industry is anticipating a requirement to manufacture designs with 0.10-micron features by the year 2005. Today's cost of constructing a modern wafer fab capable of economically manufacturing advanced designs of this nature averages \$1.5 billion. Nevertheless, as recently as late 1997, there were an equivalent of 125 such new wafer fabs scheduled to begin production between 1999 and 2003.

As many as 25 sequential photolithography steps may be required to manufacture a single semiconductor wafer. Each photolithography step imprints a different pattern in the photosensitive, organic photoresist which covers the wafer. The resulting pattern in the photoresist defines that area of the wafer which must be "masked" from exposure to subsequent wafer processing steps such as different types of plasma etch, film deposition, doping, ion implantation, etc. After exposure to these subsequent process steps, when the mask is no longer required, the photoresist mask must be thoroughly removed, or "stripped", prior to the next photolithography step. Failure to adequately clean or remove all traces of photoresist prior to the next masking step can jeopardize the functionality of the final device. This photoresist stripping process is one of the most-used processes within the lengthy, wafer fab manufacturing process.

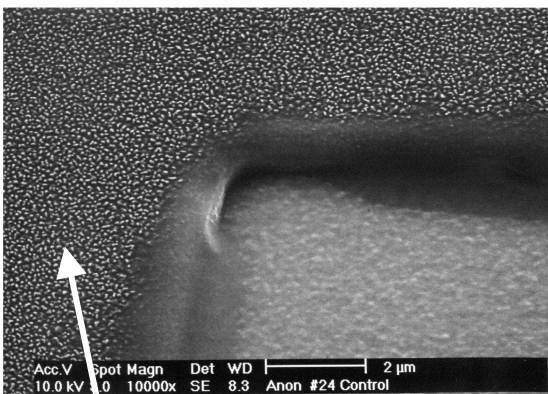
There are two major processes currently used the semiconductor industry for photoresist stripping. One is a wet process, which makes use of large quantities of hazardous or toxic liquids to wash away the photoresist. The second is a dry process, often referred to as "plasma ashing", which makes use of energetic gas plasmas to oxidize and physically "knock off" organic materials and photoresist. For particularly difficult stripping applications, these processes are often used in combination and/or repetitively until the wafer is properly cleaned.

The existing wet methods employ large quantities of hazardous, toxic liquids, such as various acids, hydrogen peroxide, ozonated water, and organic solvents, which are expensive to buy, expensive to use safely, and expensive to dispose of after use. The dominant dry method for removing photoresist, plasma ashing, uses energetic, ionized gas plasmas, which cause radiation damage and physical damage to the sensitive semiconductor wafers being cleaned. Plasma ashing also often combines the use of plasma with halogen gases, which erode the very thin silicon oxide (glass) films used in semiconductor devices. In their effort to minimize this plasma and erosion damage, stripping equipment manufacturers usually make a trade-off between reducing stripping effectiveness and throughput in order to minimize the damage. Both wet and dry methods have difficulty in completely removing resists which have been hardened by preceding semiconductor manufacturing operations such as ion implantation, and metal or oxide etching. Resist removal after these operations is particularly a problem in advanced semiconductor designs where critical dimensions are often below 0.35 microns. In designs with such small dimensions, semiconductor manufacturers are generally forced to use dry methods of stripping, accepting the unavoidable plasma and halogen damage, since wet methods are subject to surface tension effects which hinder liquid penetration of

very narrow geometries. Furthermore, in some applications wet processing may not be desirable due to the accompanying etching, or corrosion, of exposed oxide or metal surfaces. Thus, the use of plasma ashing as a solution for stripping advanced semiconductor designs, particularly memory devices which are notably sensitive to plasma damage, becomes a greater manufacturing problem as geometries become smaller, as the number of photoresist stripping steps increase, and as the overall wafer size becomes larger.

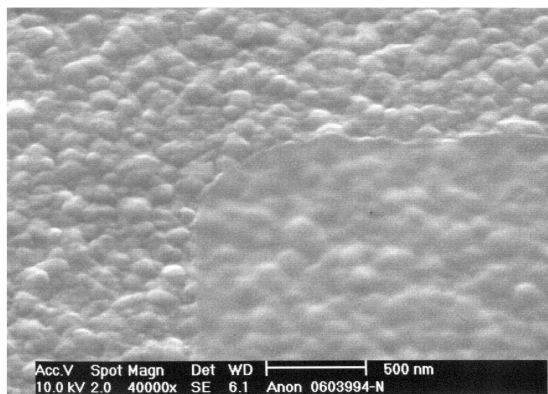
The patented technology used by ANON represents a radical departure from the current methods employed for stripping photoresist. Rather than using liquid chemicals, energetic plasmas, or halogen gases, the ANON process makes use of electrically neutral, gaseous sulfur trioxide, in very small quantities, to remove organic materials at temperatures as low as room temperature. Sulfur trioxide gas, available from several major suppliers including DuPont Chemicals, is introduced into a closed chamber containing one or more substrates to be stripped or cleaned of organic materials. After suitable exposure to the reactive processes, which may include oxidation as well as the several different sulfur-chemistry reactions which are unique in the industry to ANON's process, the organic materials on the substrate have been rendered largely removable with a simple water rinse. In the case of certain extremely-difficult-to-remove materials, it may be necessary to first remove a small amount of the overlying "crust" using a modified plasma treatment prior to stripping the remaining bulk resist with sulfur trioxide gas and water.

The SO₃ technology offers a range of technical and manufacturing advantages which set it apart from conventional, organic cleaning methods. ANON's strip/clean process is a timely response to the manufacturing needs of new generations of semiconductor devices. In this market, shrinking line geometries, increasing numbers of masking levels, increasing wafer sizes, and growing concerns over environmental impact and hazardous-waste disposal costs, are pushing the photoresist removal capabilities of current technologies to their limits. The sulfur trioxide strip/clean process offers increasingly cost-effective solutions to these needs, and offers a number of substantial, competitive advantages over conventional wet and dry photoresist stripping methods including:



BEFORE

Ion implanted photoresist (e16) before sulfur trioxide photoresist strip.



AFTER

After cleaning implanted photoresist (e16) with SO₃ and a DI water rinse. **NO WET-CLEAN, NO HALOGENS**

charging and radiation damage characteristic of dry-ashing methods in all but a small number of extremely difficult applications where such damage is largely eliminated. Thus, in all applications, the ANON process offers a plasma-damage-free method to remove photoresist which will improve product yield and reliability for semiconductor manufacturers.

Improved Gate-Oxide Integrity: The simple, sulfur trioxide and water process eliminates or greatly reduces the use of damaging plasma and the halogen gases often used in combination with plasma. Reduced plasma

and halogen damage improves gate-oxide integrity, which has been identified by the Semiconductor Industry Association (SIA) as one of the top 5 wafer fabrication process challenges which must be solved before 2005.

Control Over Metal Corrosion: The gas species employed is capable of removing organic films without damaging or corroding underlying metal surfaces and thus offers an improved capability for cleaning photoresist on wafers with exposed metal films. Current wet processes are limited in this regard by the highly corrosive properties of typical liquid stripping reagents.

Faster Stripping Times: The ANON stripping process provides much faster photoresist stripping and cycle times by replacing, with one tool, the conventional two-tool set now used for removing photoresist (i.e. plasma ashing followed by a "post-ash" residue clean in liquid chemicals). In the case of very difficult-to-remove photoresist, where these two conventional operations must often be repeated to be effective, the ANON tool offers even greater reductions in the time required to remove photoresist.

Improved Stripping Capability: The process has the ability to strip certain organic films, low-k dielectrics, and hardened photoresists and residues which are today either not removable using conventional dry-ashing processes, or which can only be removed with unacceptable levels of radiation damage, or with unacceptably slow removal rates. This improved ability to strip difficult organic films makes the process a potential "enabling" process for advanced, fine-line semiconductor devices.

Improved Waste Stream Management/Environmental Safety: The process results in a potentially huge reduction (up to 99.6%) in the volume of the hazardous operating chemicals in use and in the waste stream. An IC manufacturer who may buy, maintain while in use, and dispose of 52,000 gallons of hazardous chemicals per stripping station annually, will use less than 200 gallons in equivalent materials if the wet clean station is replaced with ANON's sulfur trioxide system.

Single-Step Stripping: With the powerful reactive capability of the process gas, the need for a combination of wet and dry stripping to remove hardened photoresists may no longer be required. Thus, a single process replaces the need for a complex combination of wet and dry stripping procedures.

Wide Process Capability: This method of stripping is effective on all commonly used photoresists, including both positive and negative resists, resists which have been hardened by heavy-dose ion implant, and resists hardened by any of a variety of different reactive ion etch (RIE) processes, deep-ultraviolet light cures, and high temperature post-bakes. The broad range of capability may reduce the need to maintain several different wet processes using several different hazardous solvents or acids to remove different resist types.

Uniform Stripping: Because the ANON process is a self-limiting process in which the reaction stops when all organic material has been processed, end-point detection is not required for most applications in order to stop the stripping process. Thus, 100% uniformity of strip is possible both across a wafer and between wafers in different process batches.

Smaller Footprint: With no requirements to generate energetic plasmas or high vacuums, and requiring a process chamber only slightly larger than the substrate itself, the stripping tool can be very small. With a smaller footprint than is now required for either wet-clean stations or for dry ashers, the ANON process tool offers a substantially lower cost of ownership in IC manufacturing facilities whose average cost is \$1.5 billion.

Scalability Upward to Larger Substrates and Batch Processing: The simple tool design also makes it relatively easy to scale the process upward to handle both larger wafer sizes and batch processing. This is a particular advantage over dry-ashing technology, where it is necessary to either maintain a uniform plasma over a large area, or to sacrifice stripping effectiveness and through-put with a single-wafer, down-stream asher.

Lower Maintenance and Operating Costs: The relatively simple process, the small footprint of the equipment, the breadth of capability of the process, and the absence of plasma generators and high vacuum systems offers both low-maintenance and low operating costs to the user.

Effectiveness with Low-k Dielectrics: The ANON process, which is primarily a sulfur-chemistry process, can strip photoresist from many popular low-k dielectrics without damage to the dielectric constant (k) and without the formation of water within the dielectric material. For this reason, the process offers very significant advantages over conventional plasma ashers which can damage the effectiveness of any exposed dielectric when oxygen is absorbed from the plasma to form water. Thus, the ANON process may enable the use of desirable low-k dielectric films that are otherwise unusable due to the damaging effects of the stripping/cleaning process.

B. PROJECT OBJECTIVES:

ANON's objective is to commercialize its sulfur trioxide technology through manufacturing and marketing gas-phase tools. However, because the semiconductor and flat-panel display industries have no experience with the use of the SO₃ gas, ANON has devised a three-stage market penetration strategy: (i) concept and feasibility demonstration, (ii) customer-specific process/application demonstration, and (iii) beta evaluation and production manufacturing.

The overall objective of the first grant period was to accomplish the goals of the stage-1 market penetration strategy. The goal was to use DoE and the CTCA matching funds, in a cost-sharing program, to design and construct an in-house R&D tool, and to demonstrate the process feasibility to prospective customers.

The objective of the extended grant period was to accomplish the goals of the stage-2 market penetration strategy, and to overcome the barriers to commercialization of the SO₃ strip/clean technology. Our goal was to demonstrate the capabilities of ANON process for customers-specific applications, and establish "beta-site" evaluation program(s) with one or more major semiconductor IC manufacturers. Following this step, ANON expects to obtain the necessary private funding for the stage 3 manufacture and sale of production tools, first to the semiconductor industry and then to flat-panel display and other new markets.

The specific objectives of the project were: (a) to design and construct an R&D tool (CRITERION-1000™) for in-house process demonstration, (b) to demonstrate the potential of the gas-phase, sulfur trioxide strip/clean process to the prospective IC manufacturers, (c) to optimize and develop specific process applications for IC manufacturers using the CRITERION-1000™ tool, (d) to design and implement process and performance tests to guide the development of the CRITERION-2000™ production tool, (e) to demonstrate the CRITERION-2000™ process capabilities, using production wafers, prior to beta-site installation, (f) to analyze the cost, energy and environmental savings resulting from the use of ANON strip/clean technology over the existing conventional tools, and (g) to develop technology transfer information for new energy and environmental products for the electronic industry.

C. TASKS DESCRIPTION:

In the original proposal to the DoE and CTCA, it was envisioned that ANON's technology would be marketed by consecutive construction of three, low-cost (Pre-Alpha, Alpha and Beta) tools, respectively targeted for installation at ANON and at a customer's R&D and production facilities. As the project progressed, and a better understanding of the semiconductor market conditions was obtained, it became clear that such a strategy would not be very effective. An incremental approach would not result in a significant entry into the market, and posed the risk of losing the window of opportunity. Furthermore, an effective strategy must take into account the unique nature of ANON's technology, the absence of previous experience with SO₃ gas in the semiconductor industry, and the challenging constraints of qualifying a new technology and tool in the new advanced fabs.

We, therefore, modified our product development and marketing strategies, recognizing that the early process and tool qualifying for the prospective customers must be done at ANON facilities. To accomplish these, the following steps were taken: (a) with improved modifications, we continued to use a previously constructed, Desk-Top, Preliminary Exposure Tool (PET) for initial process development; (b) we carried out the early concept and feasibility demonstrations on PET; and (c) we expanded the definition of the Pre-Alpha to an R&D tool (CRITERION-1000™) that, except for manual handling of the wafers, would have full capability of process development on both 6" and 8" wafers.

The new strategy would allow ANON to address a much larger global semiconductor market by qualifying its technology and tools for the new, upcoming advanced fabs, being constructed by the semiconductor manufacturers worldwide. ANON would then have the opportunity to become a significant US-based

manufacturer of semiconductor equipment, further enhancing the impact of ANON's technology on the reduction of both national and global usage of energy and environmental pollutants.

The project tasks were designed around three major efforts: (1) construction of the CRITERION-1000™ R&D tool, (2) process development and demonstration of SO₃ strip/clean application to the prospective customers, and (3) development of cost-of-ownership models and analysis of the cost, energy and environmental savings resulting from the use of ANON strip/clean technology over the existing conventional tools. These tasks were designed to complement the parallel efforts of ANON to design and develop its CRITERION-2000™ production tool, targeted for further process testing and installation at a customer site for beta evaluation.

The original task descriptions were as follows:

Criterion-1000™ R&D Tool

ANON shall construct an R&D tool with full capabilities for process development and in-house demonstration of the SO₃ strip/clean technology. Except for a manual placement of wafers into a load-lock, the tool shall be fully automated, with computer-controlled operations. The tool shall have the capability for process recipe execution and data storage and evaluation. Subtasks include:

- a. Design, construction, integration, installation and debug of the CRITERION-1000™ tool;
- b. Construction of clean-room environment; and,
- c. Design and construction of Application Laboratory and support facilities.

Process Demonstration

ANON shall demonstrate the potential of the gas-phase sulfur trioxide cleaning to the prospective IC manufacturers. The CRITERION-1000™ tool will be used for this phase of process demonstration. Subtasks include:

- a. Optimize process applications which are identified to be of interest to IC manufacturers and expand the application of the technology to new processes. Test wafers will be obtained from IC manufacturers whenever possible, or from commercial manufacturers as needed. Outside testing shall be used for data analysis, until such facilities are available at ANON's own Application Laboratory; and,
- b. Hardware and software modifications of the CRITERION-1000™ tool shall be made to accommodate the process optimization efforts.

Production wafer testing

ANON shall optimize and develop specific process applications for IC manufacturers following the initial demonstration work in process demonstration Task. The CRITERION-1000™ tool will also be used for this Task. Subtasks include:

- a. Process development and optimization efforts shall be carried out on customer production wafers. Outside testing services will be used for data analysis, until such facilities are available at ANON's Application Laboratories.
- b. Hardware and software modifications of the CRITERION-1000™ tool shall be made to accommodate the process optimization efforts.

Tool Design and Operation Testing

ANON shall design experiments that test the operation and performance of the tool and thus affect the process performance. This Task shall be performed in parallel with the design, construction and testing of the CRITERION-2000™. The CRITERION-1000™ tool shall be used for this Task, and the results shall be incorporated in the design and development of CRITERION-2000™. The subtasks below include design, construction and testing phases of the CRITERION-2000™ tool development based on:

- a. Process development results, to optimize the mode of operation of the tool, and the results of such tests shall be incorporated in the tool design;
- b. Design requirements for the tool and process development results, to optimize the mode of operation of the tool, and the results shall be incorporated as design or hardware modifications during the tool construction phase; and,
- c. Tool performance and the process development results, to optimize the mode of operation of the tool, and the results shall be incorporated as hardware modifications during the tool debugging and testing phase.

Cost of Ownership Analysis: Tool Performance and chemical, Energy and Environment Savings

ANON shall perform process performance and operation analysis on the CRITERION-2000™ production tool to determine cost, chemical usage and environmental impact. Subtasks include:

- a. Development of schedules for the use of chemicals, de-ionized water, and energy in both CRITERION-2000™ and the existing conventional tools used by the industry.
- b. Development of schedules for the disposal chemicals, water, and other wastes by both CRITERION-2000™ and the existing conventional tools used by the industry.
- c. Cost of ownership calculations based on SEMATECH or other models used by the semiconductor device manufacturers.

Technology Transfer

ANON shall prepare technology transfer materials for information dissemination about the product and the electronic industry contacts. Subtasks include:

- a. Preparation of brochures outlining the project development, funding sources, energy and environmental benefits.
- b. Development of a database of the electronic industry contacts.
- c. Development of technology presentations for suitable industry conferences, events, trade shows, etc.
- d. Development of guides to include the opportunities for new business to receive funding for energy and environmental projects.

Reporting

ANON shall submit periodic reports on the progress of the project as required by the terms of this contract. A final report will be submitted within one month from the end of the project.

D. PROGRESS REPORT:

CRITERION-1000™, R&D Tool

ANON developed its second-generation sulfur trioxide stripping tool, the CRITERION™-1000, in late 1996 based on work conducted in an earlier, more primitive exposure tool. The CRITERION™-1000 was designed specifically to permit SO₃ process development and evaluation of substrates up to 8" in diameter. The CRITERION™-1000 is a low volume, single-wafer process chamber, manual load-lock system, which allows the user to expose a substrate to at least three process gases, including SO₃ and a nitrogen purge gas, under controlled conditions of temperature, concentration and time. After exposure in the process chamber, substrates are normally washed at a separate, de-ionized water cleaning station to remove photoresist residues. Waste gases are exhausted from the process chamber and neutralized, or vented through a standard industrial gas scrubber. A computer-controller and operator display is provided with off-the-shelf software, designed to manage the processing sequence and to collect and record data. The CRITERION™-1000 tool is used to develop and optimize process recipes that address a broad range of stripping and organic cleaning applications in the semiconductor, flat-panel, thin-film head, and printed circuit board manufacturing sectors.

PROCESS DEVELOPMENT

As reported previously, initial in-house process evaluations, using customer-supplied production test wafers, have provided proof of successful cleaning of residual resist and sidewall polymers in a wide range of applications. We have demonstrated that SO₃ strip/clean technology can be used after all conventional etch and implant applications currently used in the semiconductor industry. We have also demonstrated the utility of the SO₃ strip/clean technology for the emerging low-k dielectric applications. The latter is very significant for ANON's business development, since low-k is a gating item in the SIA roadmap, and the success of ANON's technology in the low-k area can ensure its entry into the clean market.

Conventional Applications - Semiconductor

The conventional post-etch applications include:

Etch System Sales
(DataQuest, 1997)

Gate applications (Post Polysilicon etch, Silicon Nitride etch, etc.,)	41%
Post oxide etch	43%
Post metal etch	16%

Other conventional applications include:

- Post low-dose implant
- Post high-dose implant

Figures 1-4 show typical SEM (scanning electron microscope) examples of the successful applications of the SO₃ strip/clean process for the above cases, provided here with the prior permission of the prospective customers who have provided the wafers. The details of the technology and some of the more recent process results were reported in the meeting of the Society of Photo-Optical Instrumentation Engineers, Santa Clara, California, March 15-18, 1999. A reprint of the article, published in the proceedings of the SPIE conference is attached to this report as Appendix A. Additional proprietary information can be discussed with the project manager, on the need basis, under appropriate non-disclosure agreement.

Conventional Applications – Flat Panel Display (FPD)

ANON has also worked very closely with the manufacturers of FPD devices in the US and Japan to successfully demonstrate the application of the SO₃ strip/clean process for FPD device manufacturing. In particular, as part of this project, ANON devoted a significant amount of resources in its collaboration with CANDESCENT TECHNOLOGIES, a US based FPD manufacturer, with the expectation that CANDESCENT becomes its first beta-site. Unfortunately, in spite of systematic successes of ANON technology, the business considerations at CADESCENT did not allow fulfillment of this objective. However, ANON's collaboration with other FPD manufacturers, particularly in Japan, continues with a growing interest. ANON intends to license the FPD opportunity in order to maintain its focus on the semiconductor industry.

Emerging Applications – Low-k Dielectric

Low-k dielectric and copper applications are clearly in the SIA roadmap for the semiconductor industry. Following the successful demonstrations of SO₃ strip/clean process in conventional applications. ANON has begun collaborative efforts with prospective customers, manufacturers of low-k materials, as well as other semiconductor equipment manufacturers in the low-k dielectric area. Early FTIR and thickness measurement data indicated that the novel chemistry of sulfur trioxide is compatible with most carbon-doped silicon oxide or polymeric low-k materials.

ANON is currently working with major IC manufacturers to develop SO₃ process recipes for removing resists and sidewall polymers in post low-k dielectric etch applications. ANON has also established joint low-k development programs with the manufacturers of low-k materials such as ALLIED SIGNAL and DOW CHEMICALS. Joint development work has been established with NOVELLUS SYSTEMS, LAM RESEARCH and GASONICS INTERNATIONAL to integrate the SO₃ strip/clean process in the post low-k dielectric etch applications.

The list major IC or FPD manufacturers who have contributed to the process development at ANON include:

- ❑ NISSEI ELECTRONICS, LTD.
⇒ Citizen, Casio, Shinko Denki, NEC, Hitachi
- ❑ IBM/SIEMENS/TOSHIBA
- ❑ MICRON
- ❑ INTEL
- ❑ ALLIED SIGNAL (Low-k)
- ❑ SHARP (FPD)
- ❑ MOTOROLA (FPD)
- ❑ CANDESCENT (FPD)

TOOL DEVELOPMENT

CRITERION-2000™ PRODUCTION TOOL

As indicated earlier, the process development tasks in the current project were designed to complement the parallel efforts of ANON to design and develop its CRITERION-2000™ production tool. It was expected that, with proper funding, ANON would complete the development of the CRITERION-2000™ and install one such tool at a customer site before the end of the project. As reported earlier, the initial progress on the tool development in Task 3 of the project remained on target and the tool architecture was completed during the first half of the project. However, for reasons beyond ANON control, the appropriate level of funding to

ensure completion of CRITERION-2000™ did not materialize and the construction phase could not begin during the project.

In spite of the funding difficulties, ANON continued with its design efforts on the CRITERION-2000™ tool. During the grant period, ANON completed the architecture and market specifications of the CRITERION-2000™ production tool. ANON also completed the chamber design layout and the robot and interface specifications. ANON has continued with the design of the chamber and gas delivery system, qualifying robot, platform and interface suppliers, and in-house evaluation of the spin-rinse-dry subsystem. Negotiations are in progress for the supply of the platform and control software. As a result, ANON expects to complete the construction of its the CRITERION-2000™ tool in 6-9 months after the end of the current grant period. Figure 7 summarizes the product phases which were completed during the project. .

The product design concept is shown below.

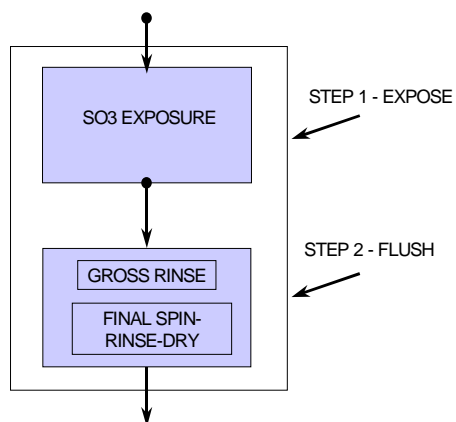


The SO₃ process chamber will be capable of exposing semiconductor wafers up to 300mm in diameter, as well as square photomasks or flat panel substrates up to 320mm x 340mm in size, to sulfur trioxide gas. The process chamber is designed to interface to wafer robots capable of handling either 200mm or 300mm wafers. By providing a symmetrical design (around the 2-robot axis), a wide range of wafer through-put and capability improvements will be possible merely by adding additional process chambers or flush/spin/rinse/dry subsystems. This design feature will allow ANON to readily accommodate the needs of different customers and applications using the CRITERION-2000™ as the foundation for future tools. CRITERION-2000™ is a single-wafer, dry-in, dry-out tool, and is expected to ship during the second quarter of 2000 for evaluation. Photoresist-covered wafers, in their cassette, will be loaded into the tool and automatically passed to the SO₃ exposure chamber where photoresist and other organic materials on each wafer will be rendered essentially soluble by exposure to a small amount of SO₃ gas. The robot will pass each treated wafer to a conventional DI-water flush/spin/rinse/dry station where the photoresist or organic film will be removed and the substrate will be dried and loaded to an out-going cassette.

COST-OF-OWNERSHIP ANALYSIS

Tool Performance and chemical, Energy and Environment Savings

ANON's SO₃ photoresist stripping process is a two-step procedure. Photoresist-covered wafers are first exposed to sulfur trioxide gas under the appropriate processing conditions in a small sulfur trioxide exposure chamber. Wafers, still covered with photoresist, are then passed to a flush process module where all photoresist and photoresist residues are washed away with de-ionized water (DI-water). The schematic diagram below illustrates the process.

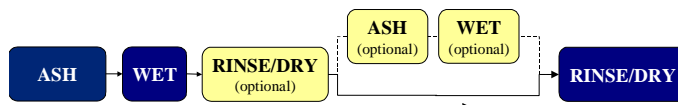


Process Integration

The ANON photoresist stripping tool is designed to incorporate both steps in a single, integrated, dry-in/dry-out tool. Thus, wafers ready for photoresist stripping are loaded into the ANON tool and automatically processed through the sulfur trioxide expose step and the DI-water flush/dry step. By integrating these process steps into one tool, the ANON process replaces plasma ashing and the follow-up post-ash clean with a single processing operation. A 30,000 wafer-start per month fab can save as much as \$2.65 each time a wafer is stripped with the ANON integrated SO₃ process¹ rather than with an asher followed by post-ash residue cleaning.

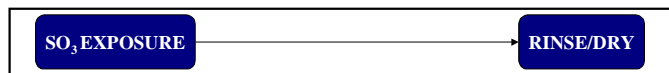
Conventional Stripping Technology

\$ 4.50/wafer pass



ANON Stripping Technology

\$ 2.51/wafer pass-\$1.85/wafer pass



¹ Actual savings per wafer is determined by the unique operating characteristics of each manufacturing facility, including actual production volume.

Cost of Ownership

To accurately estimate the cost-of-ownership for the ANON tool, it is necessary to compare ANON costs with the costs of those tools which are alternatives to the ANON tool. For most applications, the alternative to an ANON SO₃ tool is the conventional tool set made up of a **plasma asher** and the post-ash **residue cleaning tool**, or wet-bench, which is typically required for complete photoresist stripping. Using the SEMATECH 1990 Cost-of-Ownership (CoO) model, comparable operating assumptions have been entered for a 30,000 wafer-start fab running at capacity for each alternative. The model adjusts costs to account for the different capacities of the tools and calculates the comparable total costs for processing a good wafer through each alternative. For this estimate, the cost of processing a good wafer through the ANON tool has been compared to the costs of processing a good wafer first through a 2-chamber plasma asher, and then through a mid-size, automatic wet-clean station for residue cleaning.

Using comparable operating inputs, the cost for photoresist stripping with a plasma asher (\$1.73/wafer pass) followed by a wet-clean for residue cleaning (\$2.77/wafer pass) totals approximately \$4.50/wafer pass. The comparable cost for SO₃ photoresist stripping is between \$1.85 and \$2.51/wafer pass (depending on the ANON tool selected for the comparison). This amounts to a **saving of between \$1.99 and \$2.65 every time** a wafer is stripped with the SO₃ process. As illustrated below, the ANON process cost is thus less than 50% the cost of conventional photoresist stripping in all applications.

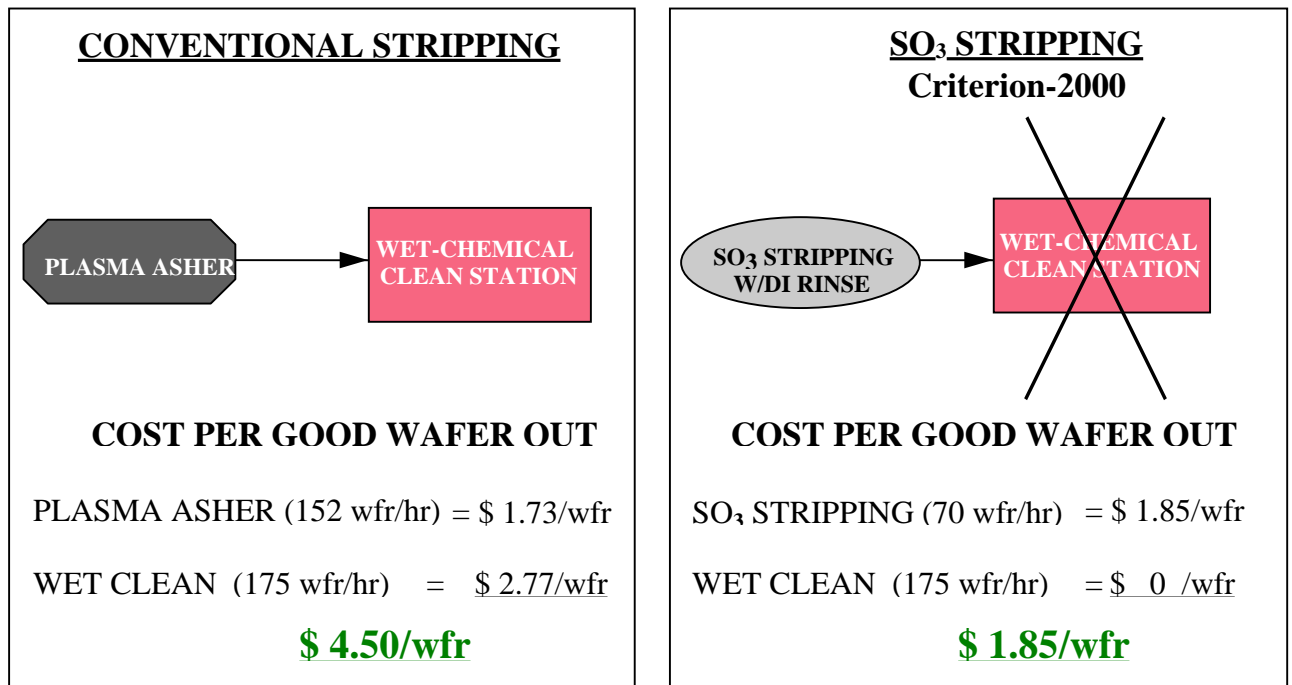


FIGURE 6: COST SAVING PER WAFER WHEN STRIPPED WITH THE ANON SULFUR TRIOXIDE (SO₃) STRIP/CLEAN METHOD (CRITERION-2000™) IN A 30,000 WAFER-START PER MONTH FAB.

Cost of Ownership and Process Integration

When considering Cost-of-Ownership as a figure of merit in evaluating processing equipment, it is worth noting that CoO calculations do not normally consider the impact of integrating several operations into one. They are generally used to compare a single piece of equipment with an alternative piece of equipment. However, the ANON photoresist stripping process, which eliminates or consolidates several conventional stripping steps into one operation, offers substantial improvements in operating metrics such as photoresist stripping **cycle time** and **work-in-process** in addition to the major improvements in CoO described above. Both cycle time and WIP can be expected to improve, sometimes dramatically, when two conventional stripping operations (plasma ash and follow-up residue wet-clean) are replaced by a single operating step (ANON SO₃ stripping). In some cases, particularly where multiple passes through ash and wet-clean are required to completely strip very tough photoresist, reductions in cycle time and WIP are potentially major improvements. This benefit is not incorporated in CoO dollar comparisons, and it must be viewed as an additional, and highly significant value advantage when considering the replacement of the conventional strip/clean tool set with a single ANON SO₃ strip/clean tool.

Input Assumptions

Cost-of-Ownership calculations are only as accurate as the input assumptions that are made, and many of these are a function of the specific manufacturing environment in which the tools will be used. Some of the major operating assumptions leading to the CoO savings discussed here are shown below in Table 1 for a 30,000-wafer start per month fab. The detailed analysis of the chemical, water and energy savings are given in Appendix B.

	(a) MAJOR, ANNUAL COST ASSUMPTIONS		
	PLASMA ASHER	WET-BENCH	ANON SO ₃ (Criterion-2000)
Reference: COOicModel.990524			
DI-WATER / system	\$ 0K	\$ 128K	\$ 13K
SPECIALTY GAS (inc.SO3) / system	\$ 66K	\$ 0K	\$ 62K
CHEMICAL SUPPLIES / system	\$ 0K	\$ 56K	\$ 0K
OTHER SUPPLIES / system	\$ 28K	\$ 63K	\$ 15K
WASTE DISPOSAL / system	\$ 14K	\$ 34K	\$ 1K
MAINTENANCE / system	\$ 20K	\$ 72K	\$ 26K
COST per WAFER PASS	\$ 1.73/wafer	\$ 2.77/wafer	\$ 1.85/wafer

TABLE 1: ANNUAL COST ASSUMPTIONS WHICH RESULT IN A SAVINGS OF \$2.65/WAFER PASS IN A 30,000 WAFER-START FAB.

The Cost-of-Ownership model used (SEMATECH 1990) considers all significant cost factors on a comparable basis, including factors such as capital costs, installation, footprint cost, **waste disposal** costs for solids, liquids and volatile organic chemical (VOC) fumes and others. Disposal costs are often hidden costs in established operations where house scrubbers and/or acid recycling capital equipment are already in place.

Furthermore, because the ANON tool eliminates the use of hazardous and toxic solvents for photoresist stripping and post-ash residue cleaning, it is particularly important to identify all the costs associated with 1) buying, 2) using, and 3) disposing of these cleaning chemicals. Personnel and material costs for using these chemicals, such as replenishment, management while in use, chemical storage and handling, training, environmental requirements, etc., must be identified and incorporated as inputs in the CoO model in addition to the costs of buying and disposal.

Thus, when full operating costs are considered, savings of between **\$1.99** and **\$2.65 per wafer pass** can be achieved by replacing a conventional plasma-ash plus wet-clean operation with ANON's single, integrated sulfur trioxide operation. If, however, practical stripping for tough photoresist, such as heavily dosed ion implanted photoresist, requires multiple passes through additional plasma ashing or wet-cleaning steps, then the savings will be even greater as each wafer accumulates repeated photoresist stripping costs.

TECHNOLOGY TRANSFER

ANON has prepared the technology transfer materials for information dissemination about the product and the electronic industry contacts, in consultation with the program coordinator. A hard copy of the materials submitted to the California Energy Commission is attached to this report as Appendix C. The following subtasks were completed:

- a) Brochure materials were prepared outlining the project development, funding sources, energy and environmental benefits. The preliminary Specifications of CRITERION-2000™ and the drafts of marketing brochures for ANON technology and products are included as Appendix C.1 to this report.
- b) A database of the electronic industry contacts was prepared. A hard copy of the database is included as Appendix C.2 to this report.
- c) A technology presentation for suitable industry conferences, events, trade shows, etc, was prepared. This material was presented and favorably received at the 2nd Annual West Coast Environmental Capital Forum, San Francisco, California, February 10-11, 1999. A hard copy of the presentation material is included as Appendix C.3 to this report.
- d) A guide for preparing business and product development plans to receive funding for energy and environmental projects was prepared. This guide will be given to DoE for distribution to interested individuals or companies. A hard copy of the guide is included as Appendix C.4 to this report.

E. CONCLUSION:

Although ANON has not been able to accomplish its ambitious goal of placing a beta tool at a customer site during this grant period, ANON has accomplished most of the major milestones of the project. In particular ANON has demonstrated that its novel technology is an enabler for the future generations of the semiconductor devices. With the help of CTCA grants, ANON has been able to transition from simple concept and technology phase to offering complete set of strip/clean applications to the semiconductor industry. These applications include both conventional and emerging (low-k and copper) needs for cleaning. The significance of ANON novel, enabling technology is depicted below.

Technology:

- **Two-Step (SO₃ / DI Rinse) Strip/Clean Process**
- **Tool Architecture for Dry-In, Dry-Out wafer**

Objective:

- **Replaces Plasma Ash & Wet Clean Processes**

The CTCA grants have allowed ANON to attract the attention of major semiconductor IC and equipment manufacturers to its technology

Appendix A

Reprint of the article, published in the
Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE)
conference,
Santa Clara, California, March 15-18, 1999.

Appendix B

Chemical, water and energy savings.

Appendix C

Technology Transfer